Enabling Technologies for Unmanned Protection Systems

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ABSTRACT

Unmanned vehicles perform critical mission functions. Today, fielded unmanned vehicles have restricted operations as a single asset controlled by a single operator. In the future, however, it is envisioned that multiple unmanned air, ground, surface and underwater vehicles will be deployed in an integrated unmanned (and "manned") team fashion in order to more effectively execute complex mission scenarios. To successfully facilitate this transition from single platforms to an integrated unmanned *system* concept, it is essential to first develop the required base technologies for multi-vehicle mission requirements, as well as test and evaluate such technologies in tightly controlled field experiments. Under such conditions, advances in unmanned technologies and associated system configurations can be empirically evaluated and quantitatively measured against relevant performance metrics.

A series of field experiments will be conducted for unmanned force protection system applications. A basic teaming scenario is: Unmanned aerial vehicles (UAVs) detect a target of interest on the ground; the UAVs cue unmanned ground vehicles (UGVs) to the area; the UGVs provide on-ground evaluation and assessment; and the team of UAVs and UGVs execute the appropriate level of response. This paper details the scenarios and the technology enablers for experimentation using unmanned protection systems.

Keywords: force protection, unmanned ground vehicle, UGV, unmanned aerial vehicle, UAV

1. PROBLEM STATEMENT

Numerous questions emerge when expanding unmanned systems from a single remotely-operated vehicle with a dedicated user to a system of systems covering multiple dimensions of the battlespace with a heterogeneous task force of unmanned vehicles of various levels of autonomy. One area of particular importance is what type of common operational picture is required to effectively perform integrated air/ground mission tasks. Should a single integrated operating interface be deployed? Or would a mission commander "global view" with individual UAV and UGV operator stations be more effective?

Additionally, it is important to note that captured imagery streams will be different, particularly with respect to orientation. Fixed-wing UAV imagery is captured in a vertical orientation, either at nadir or in an oblique orientation. Rotary-wing UAV imagery is primarily oblique. Conversely, UGV imagery is captured in an essentially horizontal orientation. As such, how can these differing orientations best be fused into a common operating picture, one that permits and promotes rapid user understanding and enhanced decision making? It is also critical that a common operating picture is geospatial in nature, one that accurately and dynamically places unmanned assets and detected targets in an easily geo-referenced framework.

A virtual three-dimensional visual display for human/robot interaction with UGVs is illustrated in Figure 1. Numerous experimental studies have demonstrated that the designed "augmented virtuality" display significantly increases user performance. Should such a display format be pursued as a common user interface for multiple unmanned vehicle types, and if so, is it even possible? It is these and other pressing questions that will be carefully and methodically addressed in a performance-based and quantifiable manner during the execution of the technology development and experiments.

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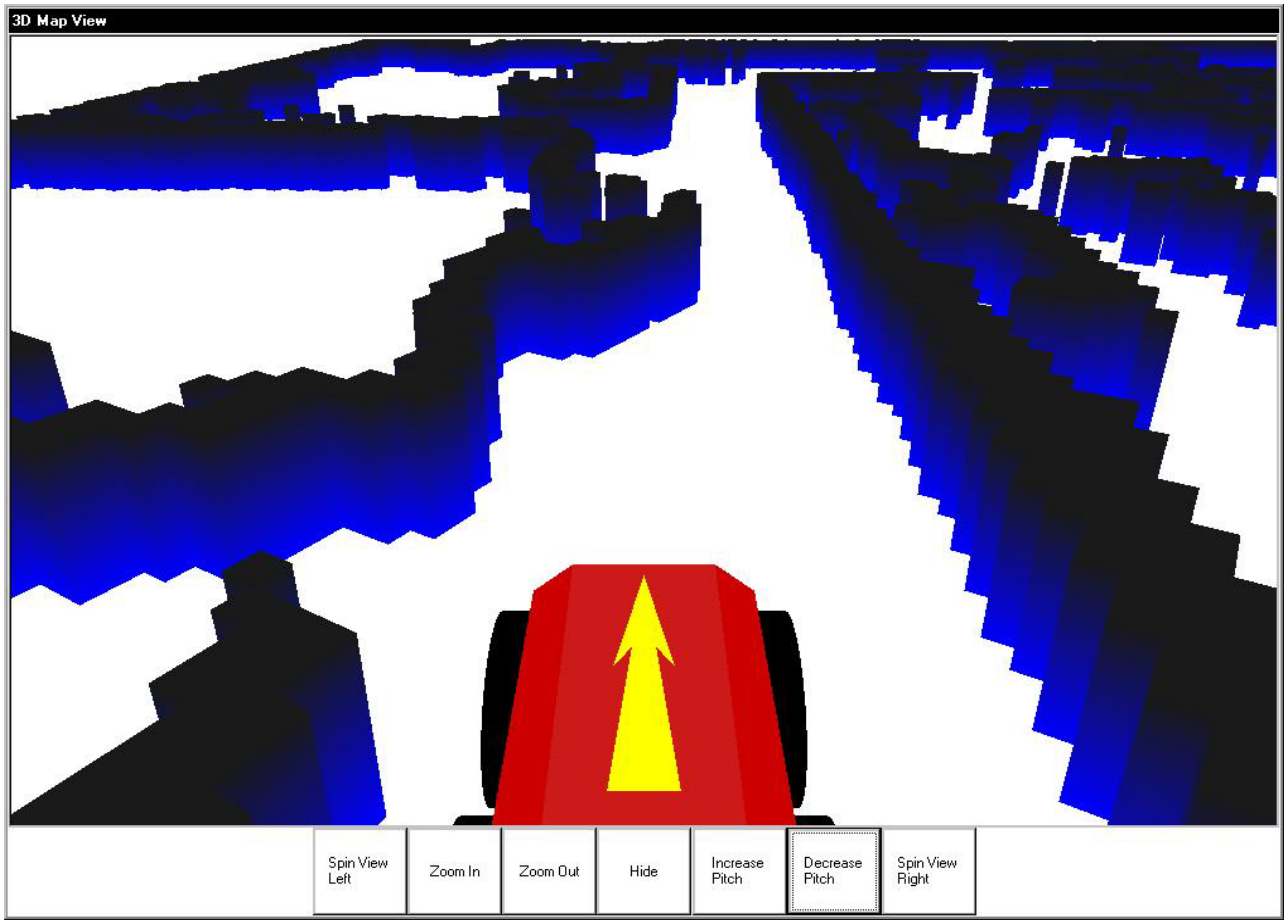

Figure 1. Unmanned Ground Vehicle Virtual Display

Of particular interest in this endeavor is how to better integrate the unique capabilities of small UAVs and UGVs, thus forming a collaborative UAV-UGV team that can effectively and jointly perform mission-specific operations. A first step in this effort is the development of a generic operational script that can be applied across differing mission scenarios. Accordingly, a generic field experiment script has been developed that includes the following major task elements for collaborative UAV-UGV teaming:

- Acquire from simultaneous, heterogeneous US Army Class II/III affordable UAVs, high-resolution geospatial imagery (e.g., still and video).
- Detect and geolocate possible target signatures via real-time sensors or via temporal changes within imagery.
- Deploy unmanned vehicles (e.g., UGVs and unmanned aerial rotorcraft) to detected targets as appropriate.
- Perform collaborative unmanned system search and detection behaviors to confirm, identify and precisely locate specific targets.
- Perform required response tasks (e.g., monitoring, manipulation, neutralization) with UGV and/or UGV assets as appropriate.

Based on this generic script, three applicable scenarios were generated dealing with Route Protection, Urban Reconnaissance and Monitoring, and Perimeter Protection. These proposed experiments will leverage heavily upon ongoing unmanned aerial vehicle (UAV) and unmanned ground vehicle (UGV) work at the Idaho National Laboratory (INL) and SPAWAR Systems Center, San Diego (SSC San Diego).

2. CAPABILITIES

The technology under development has applications for a broad range of small UGVs and several classes of UAVs engaged in a variety of mission profiles. The ability to exchange meaningful information at the appropriate level between and among unmanned systems with vastly different sensor suites and perspectives will enable effective teaming that can be brought to bear on several Department of Defense (DoD) and Department of Energy (DOE) programs. The potential to not only exchange information, but also provide an adaptive umbrella of control, will allow unmanned vehicles to support one another's capabilities and limitations across a wide variety of tasks and applications. The potential ability to represent the combined knowledge and task progress of these disparate vehicles in a single, seamless Common Operator Control Unit (OCU) is of particular importance and would enable joint unmanned vehicle technology across many different protection-oriented tasks.

SPAWAR Systems Center, San Diego (SSC San Diego) and its predecessor organizations (NRaD, NOSC, NUC, etc.) have been involved in various aspects of robotics since the early 1960's. SSC San Diego is designated by the Office of the Secretary of Defense (OSD) as the Center of Excellence for Small Robots. Our mission is to provide network-integrated robotic solutions for Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) applications. SSC San Diego has over 15 active projects for UGVs, UAVs, unmanned surface vehicles, unattended ground sensors, and unattended munitions with the focus on C4ISR.

The INL's unmanned vehicle program, consisting of small UGVs and both fixed-wing and rotorcraft UAVs (see figure 2), is currently transitioning from a technology-centric and individual platform focus, to an unmanned vehicle system and application-centric focus. Of particular interest in this transitional effort is the integration of unmanned ground and air assets into a single unmanned system concept.

Figure 2. Idaho National Laboratory Unmanned Aerial Vehicles and Unmanned Ground Vehicles

Under a Memorandum of Agreement, INL is teaming with SSC San Diego in the coordinated development, evaluation, and transfer of robotics technology.[1] This arrangement has two obvious advantages: 1) The INL Robotics Group, with similar objectives and experience, can augment the available manpower resources, allowing more technology options to be evaluated; and 2) active DOE involvement opens up another major conduit for exporting results into relevant user applications. In addition to accelerating research and development efforts as outlined in OSD *Joint Robotics Program Master Plan FY 2004*,[2] this synergistic teaming will also expedite progress towards functional objectives set down in DOE's *Critical Technology Roadmap for Robots and Intelligent Machines,*[3] thus benefiting a variety of DOE missions (i.e., decontamination and decommissioning tasks, environmental monitoring, security applications, homeland defense, critical infrastructure protection, and emergency response).

The joint effort between INL and SSC San Diego is advancing research into cooperative behaviors for UAV – UGV teams. Data from the experiments will be used to develop new technologies, Concepts of Operations (CONOPS), and Tactics, Techniques and Procedures (TTPs) to effectively integrate unmanned systems with the warfighter.

3. EXPERIMENTATION

Each generated scenario represents a specific experiment and will showcase unique technology sets and unmanned vehicle capabilities. Note that each successive experiment requires greater air/ground collaboration and teaming, thus placing increasing emphasis on the concept of an integrated unmanned "system" in a graduated developmental manner.

3.1 Route Protection/Countermine (Scheduled for FY-05)

The Route Protection/Countermine scenario will demonstrate ground change detection from a UAV combined with collaborative UGV behaviors to protect a 10-kilometer route for convoy transit. The UAV will acquire still imagery for analysis to identify possible anomalies. The UAVs will cue multiple UGVs to detect, assess, mark and neutralize targets. Scenario sequence:

a. Deploy UAV between points A & B on route. Collect two sets of images (24 hours apart) over area.
b. Perform change detection to identify and locate anomalies that indicate a possible minefield and an Improvised Explosive Device (IED).
c. Cue UGVs to converge on two locations: One a minefield and the other IED.
d. Perform collaborative UGV search behaviors to detect, assess and mark location of targets.
e. Explosive Ordnance Disposal (EOD) robots are dispatched to manipulate and neutralize detected targets.

Demonstrated technologies include:

- Time-sensitive delivery of geo-registered spatial data
- High-resolution still imagery
- Collaborative search and detection behaviors
- Countermine detection, marking and neutralization

3.2 Urban Reconnaissance and Monitoring (Scheduled for FY-05)

Urban terrain will be explored collaboratively by multiple unmanned vehicles to build a common operating picture that fuses overhead imagery with ground-based mapping. Selected buildings will be mapped and monitored both externally (UAVs) and internally (UGVs) for human presence over time. Scenario sequence:

a. Fuse geo-referenced overhead imagery of urban landscape.
b. Identify access routes to selected buildings.
c. Deploy UGVs to building via updated access paths.
d. UGVs build interior maps using Simultaneous Localization and Mapping (SLAM) technology.
e. Unmanned vehicles monitor the building for human presence or approach.

Demonstrated technologies include:

- Real-time electro-optical/infrared (EO/IR) identification, fusion and monitoring
- Common OCU with scalable representation
- Indoor / outdoor synchronized positioning
- Augmented virtuality interactive interface
- Real-time SLAM
- Human Presence Detection

3.3 Perimeter Protection (Scheduled for FY-06)

Access to a strategic location must be denied using collaboration between unmanned vehicles to assess threat beyond perimeter, predict approach vector, and intercept. Unmanned vehicle coverage will adapt to maintain perimeter surveillance and expeditiously intercept threats at perimeter. Scenario sequence:

a. UAVs maintain mosaic database of area surrounding a region of interest.
b. Unmanned vehicles detect possible threat via change-detection techniques and real-time monitoring.
c. Path of incoming threat is predicted and UGVs are deployed to intercept at perimeter.
d. Incoming threat is intercepted at perimeter. UAVs provide real-time monitoring.
e. UGVs engage potential threat and neutralize if necessary.

Demonstrated technologies include:

- Geo-referenced mosaic imagery
- Stabilization and tracking
- Probability-based vectored response
- Adaptive coverage behavior
- Unmanned vehicle collaborative patrol

Proposed FY-05 experiments will be conducted in late summer (August – September 2005 timeframe). Technology development efforts will be completed prior to conducting individual experiments. Technologies and data will feed directly into Joint Robotic Program's Family of Integrated Rapid Response Equipment, Collaborative Engagement Experiment, and Countermine Behavior projects.

4. TECHNOLOGY ENABLERS

To optimally support each experiment, a series of base technology development/integration tasks must be completed. Note many of the tasks represent the customization, maturation, and integration of already ongoing work, both within the Idaho National Laboratory, SSC San Diego, and various partnerships. Specific tasks include:

Mature and port intelligent control capabilities to small unmanned ground vehicles. Enhance indoor SLAM capabilities. Extend dynamic autonomy for collaborative behavior and control development. Transition advanced interface components into a common OCU by fusing a variety of intelligence and interface capabilities (e.g. SSC San Diego's Multi-robot Operator Control Unit (MOCU) (see Figure 3) and INL's Cognitive Collaborative Workspace) into a single, universal controller for a variety of military platforms. Port autonomy onto militarized manportable unmanned ground vehicle.

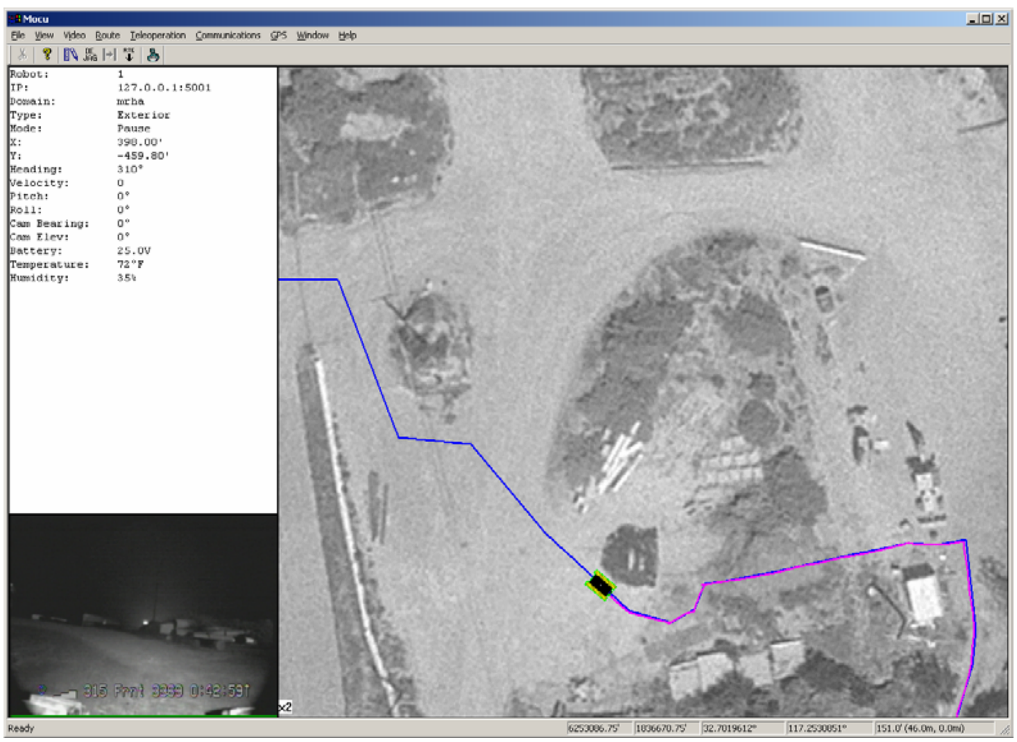

Figure 3. SSC San Diego Multi-robot Operator Control Unit (MOCU)

Mature existing Class II/III UAV technologies and capabilities for relevant mission-specific applications. Exploit and demonstrate relevant experiment-specific UAV mission capabilities. Integrate existing high-

resolution camera technologies with developed geo-registration capabilities for spatial detection of anomalous events/signatures. Mature video mosaic mapping and image stabilization for advanced situation awareness and collaborative behavior fusion during both day and night operations. Implement appropriate UAV-to-UAV and UAV-to-UGV ad-hoc communication protocols and develop collaborative behaviors for fault tolerant / extended range communications. Implement advanced health monitoring capabilities to ensure robust UAV operations.

Customize current INL Change-Detection System software to UAV/UGV-specific mission applications. Develop UAV-specific ImagePlanner capability, allowing pre-mission image capture planning. Develop UAV-specific geo-referenced imagery acquisition capability. Embed geo-referenced metadata into georegistration alignment algorithm. Embed auto-generated difference algorithm in ImageAnalyzer window. Embed generated geo-referenced imagery in Geographic Information Systems (GIS) framework. Develop relevant, experiment-specific change signature libraries.

Develop integrated unmanned vehicle ground control station to allow mission planning/operation for sequential and concurrent UAV /UGV / manned operations including image processing and analysis.

Develop field experiment performance metrics and measurement techniques. Test and evaluate unmanned vehicle collaborative behaviors, capabilities, and operations in field environments to support designed experiments.

A key outcome of this work is a better understanding of how various technology- and task-specific variables affect performance in a complex, unmanned vehicle mission scenario.

5. INTEROPERABILITY

Technology enablers for unmanned protection systems will employ spiral development to harvest and integrate innovations from the research community to move robotics technology towards a common interface and control architecture for use throughout the military.

This effort is closely aligned with the Joint Robotics Program (JRP) Technology Transfer (see Figure 4) managed by SSC San Diego - a centralized mechanism of the JRP for harvesting the best features of prior/ongoing research efforts into an optimized, standardized system that can be easily ported to robotic platforms used service-wide. To facilitate integration and ensure the success of ultimate transfer to ongoing programs, the intent is to adapt and standardize on a reconfigurable software framework that can be easily ported from one robotic system to another.

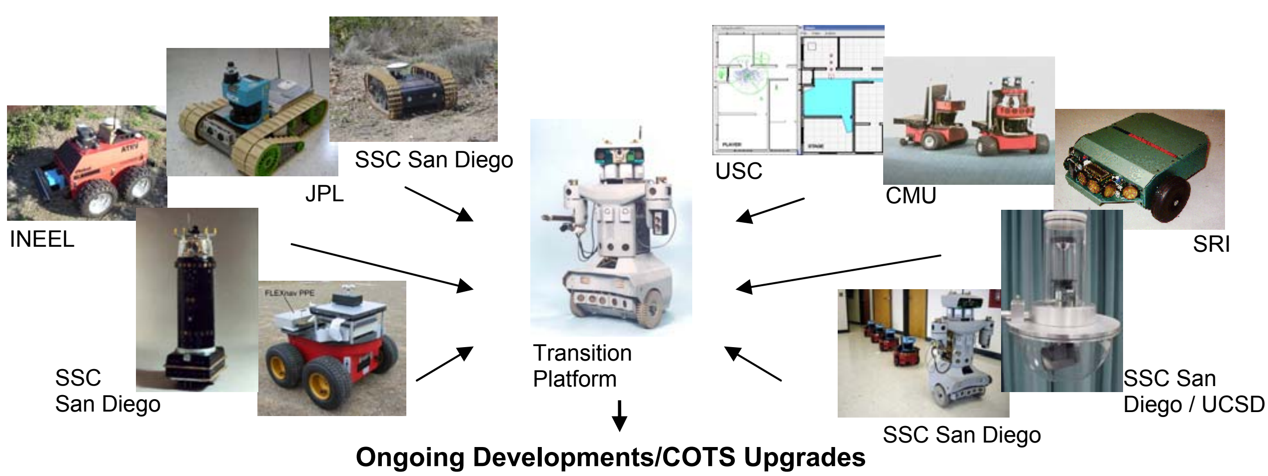

Figure 4. JRP Technology Transfer

In an attempt to exploit the best features of what has already been done, this effort will build upon the INL's Advanced Robotic Control Architecture, and combine it with the University of Southern California (USC) Player Device Server. INL's architecture currently hosts Object Detection & Object Avoidance (ODOA), Target-Following behaviors, and SLAM algorithms. USC's Player device server is not a control architecture per se, but a robot device server that allows control algorithms to access robot devices in a standard way, promoting standardization of a platform sensor framework. Player is currently being integrated and tested with INL's control architecture to allow porting to any robotic platform.

In addition, the project is further closely connected to the goals and efforts of the SSC San Diego Man Portable Robotics Systems (MPRS) program, which has demonstrated interoperability through standardization of robot platforms and payloads (common hardware). MPRS has supported Joint Architecture for Unmanned Systems (JAUS) demonstrations with hardware and software. MPRS has also developed a common wearable OCU for the US Army Night Vision and Electronic Sensors Directorate (NVESD) that controls the Urban Robot (URBOT), iRobot Packbot, and JAUS-compatible systems. Under the UGV-UAV effort, this OCU will be extended and matured to include new capabilities including indoor/outdoor operations, collaborative search and detection, and augmented virtuality. The Common OCU (see Figure 5) is specifically designed with interchangeable input/output (I/O) devices to allow for interoperability with as many different systems as possible. By combining the Common OCU with the existing INL interface components, the interoperability of both the individual robot behaviors and the interface will be ensured.

Figure 5. SSC San Diego Common Operator Control Unit (OCU)

The technology maturation and transition efforts under this program will be married closely with the JRP Robotic Systems Pool, which provides Commercial-Off-The-Shelf (COTS) robotic systems to support Concept Experimentation Programs (CEPs) and Limited Objective Experiments (LOEs), allowing users to develop requirements, operational need statements, and TTPs. The Man Transportable Robotic Systems Operational Requirements Document calls for a teleoperated system that will be enhanced to perform EOD tasks. EOD assets from the pool will be incorporated into the scenarios, with the goal to develop autonomous behaviors that can be effectively ported and transitioned to various military COTS systems of the present and future.

The experiments will also take advantage of the work being done at SSC San Diego for the JRP Collaborative Engagement Experiment (CEE) to develop and demonstrate UGV-UAV collaborative technologies in a Joint environment. CEE partners are SSC San Diego, US Army Aviation and Missile Research, Development and Engineering Center, and Air Force Research Laboratory Robotics Group. SSC San Diego is utilizing small rotorcraft UAV platforms to demonstrate automated launch, refueling and precision landing mission capabilities (see Figure 6) and show integration with a common unmanned systems control system. The resulting technologies will be integrated into the Urban Reconnaissance and Monitoring and Perimeter Protection phases of this effort.

Figure 6. Automated Launch, Refueling and Precision Landing Mission Capabilities for Rotorcraft UAV

6. CONCLUSION

The Idaho National Laboratory, SSC San Diego, and various partnerships are teaming for spiral development on technology enablers for unmanned protection systems. The teaming effort is to harvest and integrate innovations from the research community to move robotics technology towards a common C4ISR interface and control architecture for use throughout the military. A series of base technology development/integration tasks will be completed and demonstrated in three applicable scenarios: Route Protection/Countermine, Urban Reconnaissance and Monitoring, and Perimeter Protection. A key outcome of this work is a better understanding of how various technology- and task-specific variables affect performance in a complex, unmanned vehicle mission scenario. The ability to not only exchange information, but provide an adaptive umbrella of control, will allow unmanned vehicles to support one another's capabilities and limitations across a wide variety of tasks and applications. The goal is to expand unmanned systems from a single remotely-operated vehicle with a dedicated user to a system of systems covering multiple dimensions of the battlespace with a heterogeneous unmanned/manned task force.

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